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SPACE METHODS IN OCEANOLOGY

A. A. Bol'shakov

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16. Abstract

In recent years, studies of Earth from space made with specialized satellites, as well as from on board manned orbiting stations, have been assigned an ever greater place in space programs. Among the broad complex of methods used for probing Earth from space, an important role is played by methods of studying the ocean. That is what this booklet is about.

This booklet is intended for the general public, specifically those interested in the applied aspects of astronautics.

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SPACE METHODS IN OCEANOLOGY

A. A. Bol'shakov

INTRODUCTION /3*

Programs for remote study of Earth from space by using artificial earth satellites (AES) and manned orbiting space stations (OSS) have assumed ever greater importance in domestic and foreign astronautics during recent years. Important "space" information on the appearance of our planet, its atmosphere, solid surface and water envelope has been obtained. This has been made possible by diverse.research equipment installed on the Soviet and American satellites: Cosmos, Meteor, Nimbus, NOAA, Landsat and others; on the spacecraft: Soyuz, Gemini and Apollo; and on the stations: Salyut and Skylab.

A significant portion of these Spacecraft (SC) is designed for the needs of meteorology, and a fairly universal system of research apparatus for studying Earth's natural resouces has been installed on board many others. The quite multifaceted information obtained with similar SC is used in part by meteorologists, and in part by geologists, geographers, glaciologists and representatives of other Earth Sciences. But only an insignifcant portion of this information is used by oceanologists - specialists in research on the ocean.

This fact, surprising at first glance, can be explained by noting that oceanologists in the overwhelming majority of cases require very specific information different from that needed by specialists studying the atmosphere or Earth's solid shell. This circumstance, along with the ever-growing need for a comprehensive set of studies of the ocean and the demands of /4 navigation, gave impetus to the development toward the end of the 1970's in the USSR and USA of new methods of remote research and led to the creation of specialized oceanologic AES, that is satellites used only for ocean research.

The Kosmos-1076 and Kosmos-1152 AES were put into orbit under the USSR's program for research on the ocean from space, and the Interkosmos-20 and Interkosmos-21 oceanologic AES were constructed in collaboration with specialists from the German Democratic Republic, Hungary and Czechoslovakia. The USA's program for studying the ocean included putting the Seasat AES into orbit. The term "space oceanology", wide-spread and generally used at present, appeared precisely due to the launching of these satellites.

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*Numbers is the margin indicate pagination in the foreign text.

This booklet is about the problems of space oceanology, and the use of space methods and means to study and develop the ocean's resources.

Principles of Space Oceanology

In the past two or three decades, mankind has paid ever greater attention to our planet's water envelope - the ocean. There are many reasons for this, one of the most important being the urgent need to better understand the ocean itself, study the on-going processes in its depths and on its surface, calculate its mineral reserves and food resources and learn how to use it more efficiently as a highway for transportation. Now, as many countries experience increasingly acute food proteins scarcities, when resouces on dry land are being depleted and deposits of oil and other useful ores there are already exhausted, mankind sets ever greater hope on the ocean and its wealth.

Programs for studying the ocean are being broadened at an assiduous pace in developed countries. Scientific-research ships (SRS) from dozens of countries constantly plough the ocean's expanses. In our country alone, several hundred large and small SRS's take part in ocean research programs. In the 200 /5 years which have passed since scientific studies of the ocean began, SRS's have been used to examine all its corners, even the most remote, and it would seem that oceanologists should be content with the current situation. But, unfortunately, this is still not the case.

Even these great flotillas of SRS's cannot satisfy the current demands of science. The problem is that the area of Earth's globe occupied by the ocean is huge - nearly three-fourths of our planet's surface. Ocean surface area exceeds 360 million km^2, and one SRS voyage several months long can examine only a very insignificant portion of it. On a global scale, any SRS measures only one point during a specific short period of time. And although it is possible to obtain dozens of such "points" on an extensive water area by using several SRS's, "linking up" their data, frequently obtained at different times, is sometimes very difficult.

As experience in processing information from the first meteorologic AES's has shown, space methods can come to the oceanologists' aid in these cases, since they not only help consolidate measurements from individual SRS's into a unified picture, but also in many cases give fundamentally new information on the ocean impossible to collect with traditional methods.

According to preliminary evaluations, satellite systems for Earth research are so informative that in many cases their information content is significantly greater than that of

traditional contact methods. Determining ocean surface temperature with only one oceanologic AES, for example, is equivalent to synchronized measurements 20,000 SRS's. As the first experiments have already shown, observations of the ocean from space using satellites and orbiting space stations have several key features which make them very attractive to all scientists involved with ocean research.

First of all, when Earth is observed from space, you can take in a huge area in literally one glance, even with the naked eye, or with special devices. If you can take in an area of tens or hundreds of thousands of square kilometers during the flight of a spacecraft in a low, near-earth orbit, then this area /6 increases substantially as the altitude of the satellite increases, and for orbits of tens of thousands of kilometers in altitude, it reaches almost half the Earth's surface, that is, tens of millions of square kilometers.

Of course, details of Earth's surface are easily discernible only in the subsatellite point (nadir) or near it, since during observations of areas along the horizon, geometrical distortions are very great and atmospheric influences which interfere with observations increase sharply. But even if limited to angles of 45-60° relative to the vertical, areas of Earth's surface which can be observed from space are still sufficiently extensive. Figure 1 shows a graph of the relationship between the observable area of Earth's surface and the altitude of the observer's position.
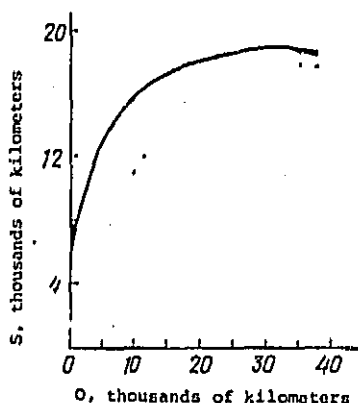
Figure 1. Relationship between the spherical diameter of a zone of Earth surface visibility and the altitude of the observer's position.

The viewing capacity of space methods view is especially graphically demonstrated by space photographs of Earth obtained using SC moving in high near-earth or lunar trajectories. Many such photographs taken by the Soviet Molniya and Zond and the American Apollo spacecraft were published in their day. Large rivers and lakes, bays, seas and continents, entire oceans, and even the largest ocean, the Pacific, were clearly visible on many of them. Evidently, these first space photographs of Earth led oceanologists to an understanding of the global character of many oceanologic problems and gave great impetus to the development of new methods of studying the ocean.

Thus, we stress once again: great viewing capacity and information content are two of the chief fundamental distinctions and advantages of space methods for studying the ocean.

As an AES moves in orbit, the Earth's surface along the flight trajectory is studied and information from scientific instruments can be recorded on board continuously or according to an assigned program, and transmitted to ground stations when the satellite passes over them. When AES's designed to study Earth's surface, and particularly the ocean, are launched, a great deal of attention is given to selecting the satellites' orbit parameters, since scanning conditions for different regions depend on this selection.

When a so-called geosynchronous orbit is selected, it /7 ensures regular passes over the same regions of Earth. First-order geosynchronous orbits provide daily satellite passes over regions of interest, while higher-order orbits provide two-day, three-day and even longer observation cycles. When a space system consisting of several geosynchronous satellites is created, observation intervals can be decreased the corresponding number of times and the necessary high rate of reception of information is still achieved.

However, a strictly geosynchronous orbit is not totally suitable for building a space system for studying the Earth. Satellites in such orbits always pass over the same regions of Earth, while other regions can drop out of their field of vision. Therefore, in practice, many AES's used to study Earth are put into quasisynchronous orbits in which the satellite passes over new regions of earth every 24 hours, and in this way provides systematic and sequential surveys of the Earth's entire surface.

To guarantee that ocean observations are always made at the same time, an oceanologic satellite can be put into a solar-synchronous orbit. In this orbit the AES always flies over each region at the same local time, thereby permitting studies where the intensity of Sun illumination of the Earth is constant. To ensure complete coverage of the entire ocean surface, an AES should be put into an orbit with a large angle of inclination to the plane of the equator. Solar-synchronous near-earth orbits have inclinations in the 95-100° range, which makes studying /8 Earth's near-polar regions possible.

Naturally, it also sound practice to put oceanologic satellites into circular orbits, like other satellites used to study the Earth's surface. This is done to obtain basic information and substantially simplify processing algorithms. Orbit altitudes for oceanologic AES already launched or under development are between 600-100 km. The lower boundary is usually·selected to provide a time span long enough for the

satellite's active life (up to one year or more), and the upper
boundary to ensure the needed field of view of Earth's surface
and desired spatial resolution of transmitted information.

At these altitudes, an AES completes 14-16 orbits around the
Earth in 24 hours, and, since the Earth rotates, the satellite
passes over new regions of its surface in each orbit. Therefore,
a projection of the orbit onto the Earth's surface (AES flight
path) covers the entire globe with a uniform grid. Figure 2
shows the Landsat research satellite's flight path for one 24-
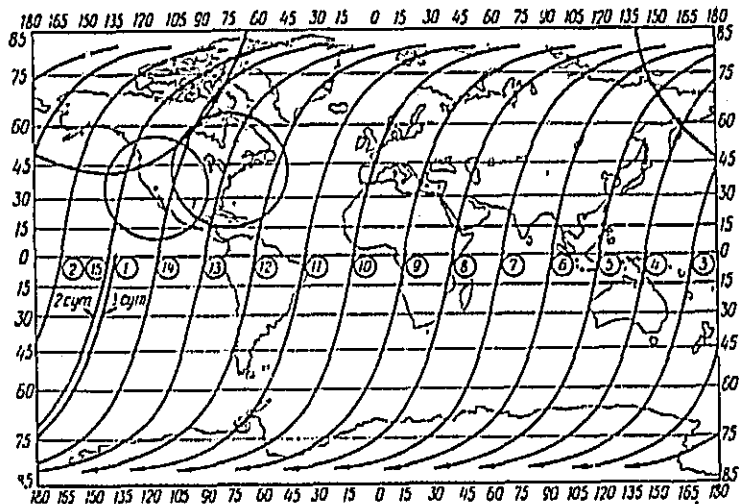hour period as an example.

Figure 2. Flight path of the Landsat research AES for
one 24-hour period. (Vertical numbers - degrees of
latitude; horizontal numbers - degrees of longitude.)

Interorbital flight path shift is maximum at the   /9
Equator, where it reaches 2800 km. Therefore, research equipment
with precisely this field of view is necessary to ensure daily
observations without ommissions. At high latitudes, the flight
paths of individual orbits intersect, and this increases the rate
at which observations of these regions are made. The daily shift
of the AES's flight track, as noted above, is selected for
continuous "coverage" of the Earth's surface using an onboard
device with a relatively narrow field of view. It is selected
separately for each specific AES.

In recent years, several experimental satellites designed to
study Earth have been put into so-called stationary orbits.
These circular orbits have zero inclination, i.e., they lie in
the plane of the Equator and their altitude above the Earth's
surface is around 36,000 km. At this altitude, the satellite
completes exactly one orbit around the earth every 24 hours, and
therefore, to the observer on Earth, it appears stationary in

relation to Earth's surface. Organizing observations of the same region of Earth with this type of AES is not complicated, but observing regions in the higher latitudes from these satellites is impossible.

All currently known space-based ocean research methods are based on satellite detection (with subsequent analysis) of the ocean's electromagnetic radiation, both its own and that which it reflects. In the latter case, a powerful source of electromagnetic radiation is frequently available on board the satellite and is used to probe ocean waters (so-called active methods). Therefore, electromagnetic waves radiated into space from the ocean's depths or surface are space oceanologists' sole source of information on the ocean.

In other words, all space methods of studying the ocean are in essence remote, or non-contact, methods. Another characteristic of these methods is that they are indirect, since the concentration of different impurities must be judged /10 from the intensity of electromagntic waves detected by the satellite. Here the values of oceanologic parameters of interest to scientists can be found by making complex mathematical calculations. This is the second basic difference between space methods of studying the ocean and traditional methods.

The characteristics indicated complicate processing of data received from space probes of the ocean, and essentially limit the area in which space methods can be used in oceanology. Processing remote sensing data requires, as a rule, use of a non-trivial body of mathematics and processing of initial information with powerful, high-speed computers. In many cases results of measurements from ordinary SRS or automated buoy stations must be used to calibrate information obtained during satellite studies. As a rule, it is generally important to do much preparatory work and make many calculations to extract useful information from space probe data.

It should also be noted here that information on the ocean, especially on its floor structure, can be obtained in principle by studying the characteristics of Earth's gravitational or magnetic field from on board a satellite, but these methods have not found use in space oceanology as yet.

Methods of studying the ocean from space developed up to the present permit investigation through all the atmosphere's "windows of transmission" (Figure 3) - the visible and near-infrared (on wavelengths of 0.4-1.2 microns), thermal infrared (3-5, 8-13 microns) and radio (1 mm-10 m) windows. Since /11 work done in each of these bands differs considerably and the methods and devices used for measuring are quite diverse, we will look separately at the potential and prospects for studying the ocean in each band.

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Bands:  0.2 0.3  0.6 0.8 1.0  2.0  4.0 6.0  10  20  40 60 100  200  0.5mm 1cm 1m 10m 100m
                                                            μ
   Ultra-  Visi-  Near-              Thermal              Radio
   violet  ble    Infrared           Infrared
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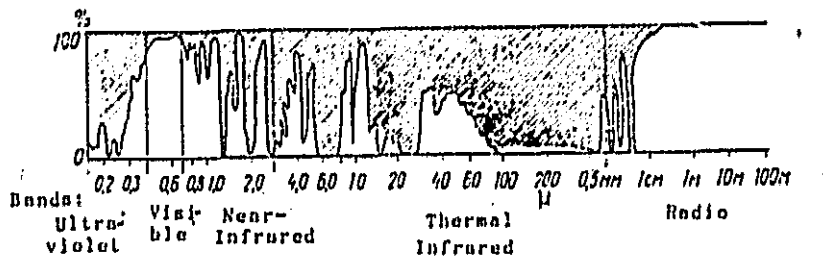
Figure 3. Transmission of electromagnetic waves by the
Earth's atmosphere in various bands.

Studying the Ocean from Space in the Visible and Near-Infrared
Bands

In the visible and near infrared bands of the spectrum, the
ocean's electromagnetic radiation is solar radiation reflected by
ocean surface or scattered by its aqueous depths. Ocean
temperature does not exceed tens of degrees Celsius, and
therefore, due to known physical laws, the Ocean's own radiation
is virtually absent in the bands being discussed.

Active optical methods are not yet sufficiently developed, so
that studies of the ocean from space in this band of the spectrum
can only be made on the illuminated side of Earth (when, properly
speaking, it is possible to study solar radiation reflected by
the ocean). The transmissivity of a clear, cloudless atmosphere
is fairly high here, and there is little atmospheric interference
during studies in the nadir or near it.

One of the simplest but most informative methods of studying
the ocean from space in the visible band of the spectrum which
does not in essence require any type of equipment is the method
of visual observation from on board a spacecraft or manned
orbiting space station. The results of these studies can be
transferred to specially prepared chart boards, or simply
sketched. In many cases phenomena observed by cosmonauts can be
photographed with cameras and thus be strictly documented.

The first visual observations of the ocean from space were
those of cosmonauts on board the first manned spacecraft. After
his historic flight, even Yu. A. Gagarin said that the ocean's
blue color seems to vary when observed from space. When looking
at the ocean from orbit, regions of different colors are clearly
visible, the coastal area stands out distinctly, and   /12
floor topography can be viewed in shallow water. The experience
of many other Soviet and American cosmonauts in space has
demonstrated the high information content of visual observations
of the ocean from space altitudes.

The methodology of visual studies of Earth from space is simple and essentially the same as that of ordinary aerovisual observations. Color shadings of dry land, clouds, and water areas are approximately the same as those seen during observations of Earth from altitudes of 10 km. Shades of different colors are easily discernible, although test measurements of cosmonauts' vision taken during flights of the Soyuz 3 - Soyuz 5 spacecraft and others showed that their contrast sensitivity usually decreases during flight by 10-20% Under space flight conditions, perception of color brightness also decreases by 20-25% in comparison with perception on Earth, especially for shades of red.

The cosmonaut's field of view during observations of Earth from space is determined by the dimensions of the spacecraft's porthole and its distance from the cosmonaut's eye. For example, when porthole diameter is 30 cm and its distance from the eye is also 30 cm, the cosmonaut's field of view during observations of Earth is 60°. When necessary, the cosmonaut can vary the field by changing his position (position scanning) in relation to the porthole.

During observations of the ocean from space great changes in color tone are especially noticeable in the ocean's frontal zones: where water masses with different degrees of saturation with coloring suspensions meet; on the boundaries of major currents; in shallow water. Thus, for example, warm tropical waters poor in life have a saturated blue-green color, while cold waters of temperate latitudes are bright green due to a high concentration of diverse microalgae. Therefore, zones where these waters mix are distinctly visible.

According to V. Ryumin, flight engineer on the Salyut-6 OSS, visual observations of ocean color are best made when the Sun is high, since color contrasts in ocean waters are especially noticeable then. When the sun is low, the entire ocean seems to be one color, a dark blue, but, on the other hand,   /13 surface phenomena such as eddies, currents and wakes of internal waves appear more clearly.

The list of phenomena and objects observable from space by eye is quite long. From altitudes of several hundred kilometers the boundaries of debris cones where muddy river water enters the sea are clearly defined; floor topography is visible in shallow water; the characteristics of mesoscalar ocean eddies, that is, those having dimensions of several hundred kilometers, are ascertained; even types of plankton in bioproductive regions is discernible; the trail of ships' wakes is noticeable, and so forth.

During observations of the ocean from space, studies are conducted over a wide, constantly changing range of viewing

angles and illumination intensities. Here the cosmonaut's eye
looks over an extensive area of the ocean's surface and examines
objects which stand out against its background in greater detail.
Due to the high adaptability of human eyesight, the cosmonaut is
able to glance at and fix in memory details of interest, even if
time spent observing them is no more then several seconds. The
selective capacity of man's eyesight and his logical analysis of
observation data give the cosmonaut-researcher a capacity for
complex perception of observed phenomena which at present cannot
be achieved with any type of apparatus.

The great value of visual observations of the ocean from
space is due to the human eye's perfection as a measuring
instrument, as well as man's ability to instantaneously process
perceived images, separate the essential from the non-essential,
note new features of well-known objects and catch puzzling and
unusual phenomenon. A cosmonaut's observing abilities increase
especially sharply after good preliminary training, and it is
most probable that, in the near future, cosmonaut-oceanologists
will appear as crew members on orbiting space stations.

The effectiveness of visual observations of the ocean from
space increases significantly during long flights if the same
region is observed repeatedly. In this case cosmonauts
immediately recognize familiar regions and note changes which
have occurred in them. This fact was noted by many space crews,
especially the Salyut-6 sation's main crews.   /14

Cosmonauts observing the ocean from space sometimes note
phenomena and objects that perplex ocean optics specialists.
Even during flights of the first spacecraft it was noted that
cosmonauts could distinguish small-scale objects, even those as
small as individual ships, against the background of the ocean.
For a long time this seemed impracticable, but scientists were
later able to explain this phenomenon. They learned that they
had underestimated the adaptive characteristics of human eyesight
and that the acuity of cosmonauts' vision can increase
appreciably during space flight.

Several times cosmonauts reported that they clearly saw
underwater mountain ranges in the ocean at depths of several
hundreds or even thousands of meters. Optics specialists assert
that this is impossible, since even the most transparent ocean
water completely absorbs sunlight at depths of only several
hundred meters (and it therefore follows that directly viewing
the ocean floor at great depths is impossible). Analysis of this
interesting data shows that here cosmonauts are apparently
observing some other phenomenon somehow related to ocean floor
topography, or simply resembling it.

It is possible that this is how irregularities in ocean surface contour related to floor topography, recently discovered with space altimeters, look when observed from space. Or perhaps it is vertical movement of ocean waters flowing along the underwater relief and making the hidden visible as they surface. It is true that variations in spatial distribution of suspended mineral and organic matter concentrated in the density discontinuity layer at depths of 30-100 m are plainly visible from orbit.

A layer of discontinuous density develops at these depths during the summer and different impurities can accumulate in it. When observed from great heights (from space), the spatial distribution of this suspended, or foreign, matter can have a structure which might be perceived as the image of objects /15 familiar to cosmonauts (in this case, mountain ranges which they see during each orbit when flying over real mountains). However, it is possible that this is simply an optical illusion similar, for example, to the way astronomers had long "seen canals" on Mars through their telescopes, which, in fact, they did not.

There is still much here for science to clarify.

While studying the surface of the ocean at small sighting angles and near the boundary of areas highlighted by the Sun, cosmonauts sometimes observe irregularities in ocean surface contour in the form of individual swells and troughs. Thus, according to data from the Salyut-6 station's third main crew, V. Lyakhov and V. Ryumin, on one orbit they saw some sort of "rearing up" of water in the Indian ocean 250-300 km from the coast of Africa. The narrow strip of "reared up" water was around 100 km long and only 1.5-2 km wide. They could even see its shadow, or something like it, on the water. The cosmonauts had the impression that two swells had crashed together in the ocean and risen high into the air.

Oceanologists are still unable to find a clear explanation for this interesting phenomenon seen by the cosmonauts. Perhaps it is the appearance of internal waves visible from orbit, the above-mentioned irregularities in ocean surface contour, or perhaps the result of hydrodynamic interaction between ocean currents. In any case, these phenomena are of great interest to oceanologists and many additional experiments are necessary to understand them clearly.

Most recently, the so-called visual-instrumental methods of studying the ocean from space have been improved, and this has broadened the capabilities of human eyesight. In the simplest case, binoculars and telescopes can be used to study small-scale phenomena or objects, for example. Opportunities for observing the ocean at low illumination and on the night side of orbit are broadened significantly by nocturnal vision instruments with optical-electronic light intensification.

There are also instruments with which cosmonauts can obtain accurate colorimetric evaluations of objects studied. The simplest ones can be common tables of ocean water coloration or a set of vials with different colored water (like the Forel-Ul scale of chromaticity, widely known in classical oceanology). Optical-electronical colorimeters can be used when more accurate measurements of color are desired.

In general, visual observations of the ocean from space are still going through a period of methodical formation, but it is already clear that, when properly organized, they will offer oceanologists much useful and interesting information.

One of the most developed methods of studying the Earth's surface from space is space photography. Cameras specifically designed for work in space are set up on board automatic satellites and manned stations and as of the present, hundreds of thousands of photographs of Earth's surface have already been obtained, photographs of the ocean among them.

Even common black and white photographs can contain much oceanologic information, and colored ones even more so. Much of what a cosmonuat's eye can see, with the exception of low-contrast objects, can be feasibly imprinted on a space photograph. On the other hand, modern photography's informative capacity is in many cases greater that of human eyesight, and things invisible to the naked eye can be detected with special types of photography.

When information on the ocean is obtained in the form of photographic images, the ease with with ocean objects can be made out depends on their contrast (or relative excess brightness). Against many backrounds, an object is only visible when its contrast is greater than a certain threshold value determined for specific conditions. This threshold value is considerably different for different observation systems. Thus, the human eye, despite a slight decrease its contrast sensitivity in weightlessness, makes out objects with contrasts on the order of 1-2%. In this sense photography and television systems are much less sensitive and their contrast threshold value lies in the 10-20% range.

This, by the way, is the reason that several oceanologic objects which cosmonauts noted and photographed during visual study sessions cannot be made out on photographs they took.

Existing space photography systems have photographic lenses with focusing distances of several centimeters or tens of centimeters. Pictures are taken on film from 6 to 30 cm wide, which permits imprinting up to several million square kilomters of ocean surface on one frame with good spatial resolution. Resolving power of modern photography systems is fairly high, and

ocean objects with linear dimensions of several meters can be made out on photographs taken with them.

When black and white photographs are taken on isopanchromatic film, the relative brightness of objects is measured, as it were, in a wide range of wavelengths (400-800 nm). In this case objects with the same integral brightness but different chromaticity (red and blue objects, for example,) are not differentiated, as those familiar with the principles of photography well know. In order to accentuate the difference in spectral patterns of different natural formations, synchronous surveys can be taken in two or three spectral zones.

For example, when photographs are taken in areas of the spectrum to which the human eye's visual receptors are sensitive - blue, green and red, the object's image is obtained in natural color. All common color photography, which is analogous to man's trichromatic vision and approximates its informative character, is built on this principle and the use of three-layered light-sensitive photomaterials. In recent years new and more informative methods of studying Earth's surface from space have been used during photographic surveys, principally spectrozonal and multizonal photography.

When spectrozonal photographs are taken with multilayered photomaterial, the principles of common color photography are used, but the layers' spectral sensitivity is such that   /18 objects of interest to scientists are better revealed. For pictures of the ocean taken from space, one of the film layers can be made sensitive to rays of the near-infrared band with wavelengths of up to 1 micron. As a result, a series of interesting tasks can be carried out which would be impossible with visual or ordinary photographic methods.

Chief among these tasks, for example, is detecting and studying ocean oil pollution and evaluating ocean bioproductivity. In the near-infrared band, clean water completely absorbs incident light, but contaminated water reflects it, even if only a little. Algae content and that of other suspended matter affects backscatter from water in this band in a similar manner. For this reason, patches of ocean oil pollution and those regions with high impurity content appear as characteristic pink spots on spectrozonal photographs (for example, on Soviet-made films SN-6 and SN-8) .

Multizonal photography, based on taking synchronous photographs of natural objects in several narrow spectral intervals, offers even greater potential for distinguishing fine spectral differences between different natural formations. The MKF multizonal space camera, developed by specialists from the USSR and GDR, is one of the most refined cameras of its class. It can be used to simultaneously photograph Earth's surface in six spectral zones.

Zonal light filters with maximum light transmission on 480, 555, 600, 665, 730 and 840 nm wavelengths were used in the first experiments on studying Earth's resources. The width of each photographic zone was fairly small and no greater than 40 km. Spectral sensitivity curves for all the MKF-6 camera's photographic bands are shown in Figure 4. When taking photographic surveys from an altitude of 250 km, each picture captures a 115 x 165 km area of the Earth's surface with local resolution on the order of 10-20 m. Different types of photographic materials are used with the MKF-6 camera, and a photometric wedge is printed in each frame at the moment the picture is taken for photometric calibration. /19
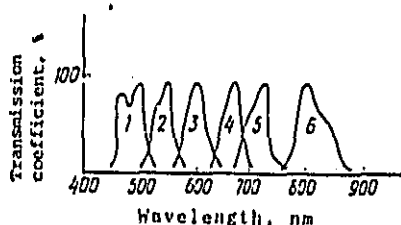

Figure 4. Spectral sensitivity curves for the MKF-6 camera's photographic bands.

The first flight tests of the MKF-6 were made in 1976 during the the "Raduga" experiment on board the Soyuz-22 spacecraft. At present, this is the camera officially installed on all Salyut-type stations.

Analysis and interpretation of photographic images of the ocean obtained in individual zones is made with the MSP-4 quadrizonal projector, which projects enlarged, combined images on a special screen. Screen images can be in actual or representative colors.

Use of multizonal priciples when photographing the ocean permits detection of fairly fine variations in ocean surface color and particularly facilitates studies of the distribution of increased bioproductivity zones on a worldwide scale. Naturally, multizonal space cameras must have high absolute (up to 15-20%) and relative (up to 3-5%) photometric measurement accuracy to complete these tasks, but this is easily within the reach of their current state of development.

However, while possessing all the above advantages, photographic methods of studying Earth from space have one short-coming due to the necessity of returning exposed photomaterials to Earth for subsequent developing. This holds especially true for methods used to study the ocean, which must be highly efficient and obtain information at a rapid pace due to the great changeability of on-going ocean processes.

To solve many oceanologic problems and, more importantly, to forecast different ocean phenomena, oceanologists must obtain information with delays of no longer than a few hours and /20 at a rate of up to several times a day. Naturally, photographic methods are of no help to oceanologists in this case and the given problem can be solved only by using television systems.

The first television images of the Earth's surface from space were obtained at the beginning of the 1960's when the first meteorologic satellites were launched. Although these images had low spatial (1-2 km) and spectral (8-16 integral brightness gradients in the 500-800 nm area of the spectrum) resolution, they helped define ice-covered sections of the ocean, detect shallow water areas, study major ocean currents, etc.

Television systems with so-called mechanical ray scanning have become quite common in the past few years. In this system (Figure 5), scanning Earth's surface along the flight track is made possible by the movement of the satellite itself, and in the lateral direction by oscillation of a television receiver or special mirror.
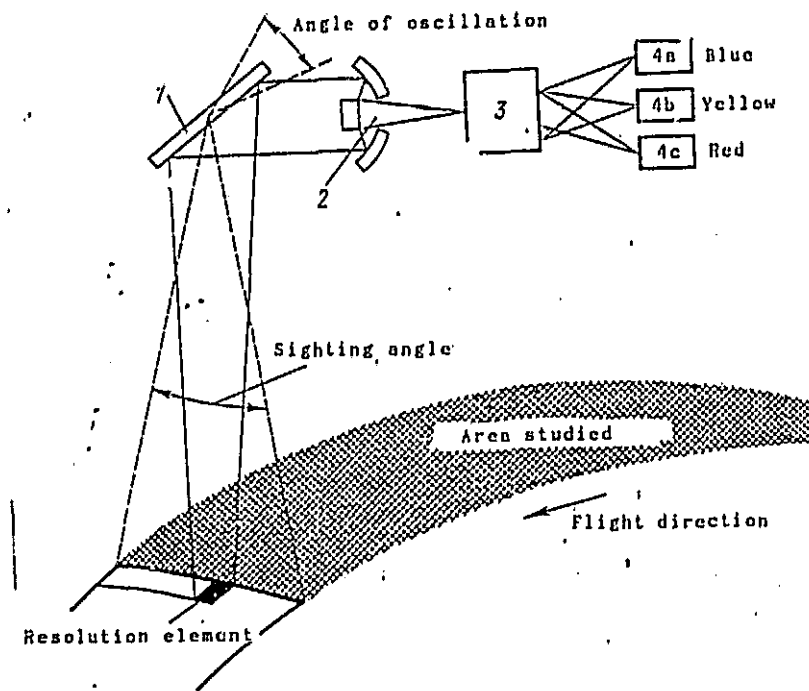
Figure 5. Operating principle of a multizonal television scanning system: 1 - oscillating mirror, 2 - mirror object, 3 - light filter, 4 - radiation receivers.

In this system, spatial resolution is determined by the optical system's momentary field of view, and spectral resolution is determined by dividing filter characteristics and radiation receiver sensitivity. The width of the field of view depends on satellite altitude and the turning camera's angle of oscillation. Information from the television system can be transmitted to Earth instantaneously (in real time), or recorded with onboard tape recorders for relay at the appropriate moment when the satellite passes over a communications point.

Multichannel space scanning systems with spatial resolution of better than 100 m and spectral resolution of better than 100 nm appeared at the beginning of the 1970's. It is now possible to obtain information comparable to that from photography systems in photometric and other characteristics with these devices.

Television images of Earth's surface transmitted by the Landsat satellite, for example, have a spatial resolution of around 70 m when frame area is 185 x 185 km. Landsat's electromechanical scanning television system took a   /21 synchronous photographic survey of Earth's surface in four zones of the visible and near infrared bands of the spectrum (in the 0.5-0.6, 0.6-0.7, 0.7-0.8 and 0.8-1.1 micron wavelength zones), which, after appropriate computer processing, provided images of the underlying surface in so-called representative colors with good color gradation of different natural formations.

These systems have already been used to tackle a significantly broader range of oceanologic problems. Specialized scientific literature cites data which says that on several images transmitted by Landsat, regions of the ocean polluted by petroleum products and industrial wastes are defined; previously unknown regions of increased bioproductivity are   /22 revealed; shallow water sections can be detected, as well as zones where river and sea water mix; the wakes of internal waves are visible, etc.

Here it can be noted that photographs in the short wavelength band (0.5-0.6 microns), where the absorption of light in ocean water is minimal, permit better studies of underwater topography and water bioproductivity, while photographs in the long wavelength band (0.7 - 0.8 and 0.8 - 1.1 microns) provide clearer images of surface phenomena. Finally, combined processing of long and short wavelength data facilitates effective detection of ocean surface polluted by petroleum products.

The fact that information can be easily entered into a computer and processed (according to fairly complex algorithms) to eliminate geometric, photometric and other distortions, is yet another advantage of space television systems. When video-information is computer-processed, final results can be obtained in any cartographic projection by using data from a random number

of spectral zones, and this increases the information content of remote probe data significantly.

Space photo and television information has already helped solve several interesting oceanologic problems. One of these, for example, is uncovering and studying the dynamics of the above-mentioned internal waves. These waves originate at depths of several tens of meters, where density discontinuity occurs in subsurface water layers. They determine the passage of sound in the depths of the ocean, and the safety of underwater vessels. Many specialists believe that internal waves caused the wreck of the American atomic submarine Thresher several years ago.

Studying these waves with traditional contact methods requires large amounts of time and the use of many SRS's. They are often immediately visible on space photographs, and several of their parameters can be measured. Internal waves originate in ocean depths and cannot be immediately observed on the surface, but several concrete phenomena related to them permit their detection on space photographs. There are at least three /23 characteristic forms of interaction between internal waves and the ocean surface which make these waves visible.

Oscillating migrations of water particles in internal waves can reach the ocean surface and, interacting there with the current and wind, can affect the form and distribution of ripples and smooth water. In this case, moving bands of ripples and smooth water will be observed on the ocean surface.

This pattern can sometimes even be seen with the naked eye when observing the ocean surface from a high shore. The width of these strips can reach several hundred meters, and the length, many kilometers. Measurements made by SRS's show that crests of internal waves are located underneath ripple-covered bands and troughs under smooth areas. The bands of ripples and smooth water reflect sunlight differently and this is why they appear on space photographs.

The uneven distribution of surfactants which affect the form of surface waves and reflecting properties of the ocean surface may be related to the movement of water particles in inner waves as they surface.

In coastal regions, especially where the surface layer of the ocean is quite turbulent, internal waves can be detected on photographs because on wave crests the more transparent water of the lower level rises closer to the surface (on space photographs these crests appear as darker tones). The layer of turbid water is thicker in the troughs, and they therefore look lighter on the photographs.

Internal waves are visible on many space photographs obtained by crews of the Soyuz and Apollo spacecraft and the Salyut and Skylab stations. They can be detected, for example, along the coast of Colombia, the Galapagos islands, Kamchatka, in the Arafur Sea and several other regions.

However, despite their overall high information content, neither photographic nor television methods in their present form can help with several oceanologic tasks which require high spectral resolution of raw data. Studying the distribution of chlorophyll on a worldwide scale is one such task.   /24 Even if a qualitative picture of its distribution in the ocean can be obtained using photo-television methods, finer spectral methods are needed for a qualitative evaluation.

Chlorophyll is a green substance which transforms sunlight into biomass. Chlorophyll is the basis of life on Earth; it enters into the composition of plant life on dry land and of microscopic ocean algae, or phytoplankton. Therefore, studying its distribution is extremely important, and can be done with remote methods.

From laboratory research we know that chlorophyll has two clearly marked sunlight absorption bands. The stronger of the two lies in the blue-violet area of the spectrum and corresponds to radiation with wavelengths of 0.42-0.46 microns. The other lies in the red area and corresponds to wavelengths of 0.66-0.70 microns. In the 0.5-0.6 micron area, chlorophyll reflects incident light intensely, and this determines its saturated green color (as it does the green color of all plants). If fine measurements of the spectrum of light radiation scattered by ocean depths are made, the concentration of chorophyll contained in the water, or that of phytoplankton, can be evaluated from this spectrum's characteristics.

This is the basic concept behind remote measurements of this oceanological parameter, but in practice several difficulties. are encountered. First, in many cases chlorophyll's blue band is simply not visible in the spectrum of sea water radiation. It is masked by the absorption of dissolved organic matter whose concentration, although it can be correlated with chlorophyll content, hinders measurements nonetheless. Second, when using a given method of space research it is important to take the distorting effect of the atmosphere into account. To decrease this effect it is important to measure the intensity of ocean surface radiation accurately, in narrow spectral bands 10-15 nm wide near the absorption bands. This task can be done by using sufficiently high-speed multichannel spectrophotometers.

The first space spectrophotometric studies of ocean surface for the purpose of evaluating its bioproductivity   /25 were made on the Salyut-6 station with the Bulgarian Spektr-15

manual spectrophotometer, and with the Interkosmos-20 and Interkosmos-21 satellites, which had the 13-channel MKS-13 spectrophotometer developed by Soviet and GDR specialists on board. The MKS-13 spectrophotometer works on seven "sea" channels, centered relative to wavelengths of 415, 450, 485, 535, 570, 620 and 675 nm, and on six "atmospheric" channels, centered relative to wavelengths of 758, 760, 763, 777, 794 and 823 nm. At 50% signal intensity, "sea" channels are 10 nm wide, and "atmospheric" channels - 1.5 nm.

This zone selection permits evaluation of radiation intensity in chlorophyll absorption bands and near them, as well as determination of solar radiation absorption in the atmosphere, which is necessary for correcting data from "sea" channels. The first results from processing data from ocean probes made with the MKS-13 spectrophotometer confirmed this method's fundamental potential for studying phytoplankton distribution on a worldwide scale.

In September, 1978, the American Nimbus-7 experimental satellite was launched, and among the instruments installed on board was a multichannel spectrophotometric scanning device for studying distribution of ocean color characteristics in coastal zones. This instrument provided images of the ocean in five zones of the spectrum - on wavelengths of 433, 520, 550, 670 and 750 nm. To process information obtained with this instrument, fairly effective algorithms were developed which made elimination of atmospheric interference possible. Determinations of chlorophyll concentration with this instrument were up to 50% accurate, which is comparable to the accuracy of ordinary contact methods and satisfies practical requirements.

Current evaluations leave no doubt about the promise of spectral methods for studying the distribution of life in the ocean. Apparatus built on the principles described above are scheduled to be installed on spacecraft currently being designed: the Seasat-2 and MOS-1 satellites, the Skylab   /26 station, and other spacecraft whose launches are planned for the second half of the 1980's.

All the optical methods for studying the ocean from space enumerated above are, in essence, passive methods based on studying solar radiation reflected by the ocean's surface or scattered by its aqueous depths. Active methods for working in this area of the spectrum, involving irradiaton of the ocean from on board a satellite, were not developed for a long time due to serious limitations in power engineering; recently, however, information has begun to appear on the potential and prospects of probing the ocean from space with so-called "lidars", or optical range laser locators. Preliminary evaluation shows that these instruments could accurately accomplish space altimetry tasks (with accuracy up to several centimeters). In addition, use of

"lidars" in the blue-green area of the spectrum could make depth soundings down to tens or even hundreds of meters possible.

STUDYING THE OCEAN FROM SPACE IN THE THERMAL INFRARED BAND OF THE SPECTRUM

In the near-infrared range of the spectrum there are two "windows of transmission" in the atmosphere, on wavelengths from 3-5 and 8-13 microns, through which space studies of the ocean can also be made. In the first of these "windows", the ocean's own thermal radiation is commensurate in intensity with re..cted solar radiation, and therefore measurements of ocean temper..ure must be taken only on the dark side of orbit. In the second "window", reflected solar radiation is virtually absent, and thermal measurements do not depend on illumination of Earth's surface by the Sun.

Atmospheric transmissivity in these "windows" is quite high, but to take accurate temperature measurements, absorption of radiation by Earth's atmosphere must be taken into account. To accurately determine the atmosphere's transmitting function it is necessary to know the vertical profiles (distribution with altitude) of air temperature and humidity, as well as vertical distribution and optical characteristics of the aerosol (cloud cover). Accurate evaluation of these values is possible   /27 only with additional data from probes of the atmosphere in the visible, near-infrared and microwave bands of the spectrum. For approximate calculations of underlying surface temperature, simple evaluations of atmospheric interference are sufficient.

The number of hydrophysical parameters which can be determined by probing the ocean from space in this area of the spectrum is very limited, but, in return, there is one among them which has great practical significance - the temperature of the ocean's surface layer.

Accurate knowledge of the this temperature's distribution makes accomplishing many tasks possible: defining the boundaries of ocean currents and the location of frontal zones, tracking the movement of mesoscalar ocean eddies, finding regions of heightened bioproductivity, evaluating the interaction between ocean and atmosphere, and several other important tasks.

Information on surface layer temperature is carried by infrared thermal radiation from the ocean surface. This radiation's intensity related to normal (thermodynamic) temperature by the well-known Stephan-Boltzmann law. Since intensity can be measured by devices installed on board a satellite, it follows that the ocean's temperature can also be measured this way. The basic instruments used to study the ocean in the thermal infrared band are scanning radiometers, with which

information on ocean surface temperature is obtained in a convenient, visual form.

The operating principle of an infrared scanning radiometer is similar to that of the ordinary scanning instruments used in the visible band previously described, and recently both have often been structurally combined into one instrument. Signals received on Earth from satellite infrared radiometers are transformed in special devices into light source intensity, with which ocean temperatures are recorded on ordinary black and white photographs. Therefore, the outward appearance of space radiometric information in this band is like that of ordinary black and white photographs, and on it sections of the ocean with different surface temperatures are seen as different shades /28 of grey (and example of such images is shown on the final cover page).

This method of presenting information from thermal probes permits rapid construction of temperature charts for the ocean surface with 1-3 K temperature discreteness. To obtain more detailed data, the information obtained from radiometers can be processed in a computer and presented in any form convenient for further use.

Basic problems arising when processing radiometric information are eliminating atmospheric interference and putting information into a form convenient for and familiar to oceanologists. The problem is that oceanologists use theromodynamic water temperature, measured with a mercury or other contact thermometer at a wave of thoroughly defined depth (0.5 m), as the temperature of the ocean's surface layer. But infrared band radiometers measure the radiation temperature of a thin radiating surface film (skin layer, or boundary layer, or cold film) no more than tens of micrometers thick. However, as accurate measurements have shown, this thin boundary layer, whose total thickness is only a few centimeters, aways has a positive or negative temperature gradient of 2-3 K (Figure 6), depending on hydrometeorologic conditions.

Therefore, even in an ideal instance, absence of atmospheric interference, for example, there will always be a difference between readings from an ordinary thermometer lowered to a depth of 0.5 m and those of a radiometer measuring the temperature of a surface film a few micrometers thick. In addition, when remote sensing data is being interpreted, it is important to take into account that satellite measurements correspond to intergral flow from a certain area, while traditional measurements with a contact thermometer are taken at one point. This might also be a source of discrepancy between the instruments' readings.

Often this natural difference in temperatures is considered a method error, and it is said that space infrared /29
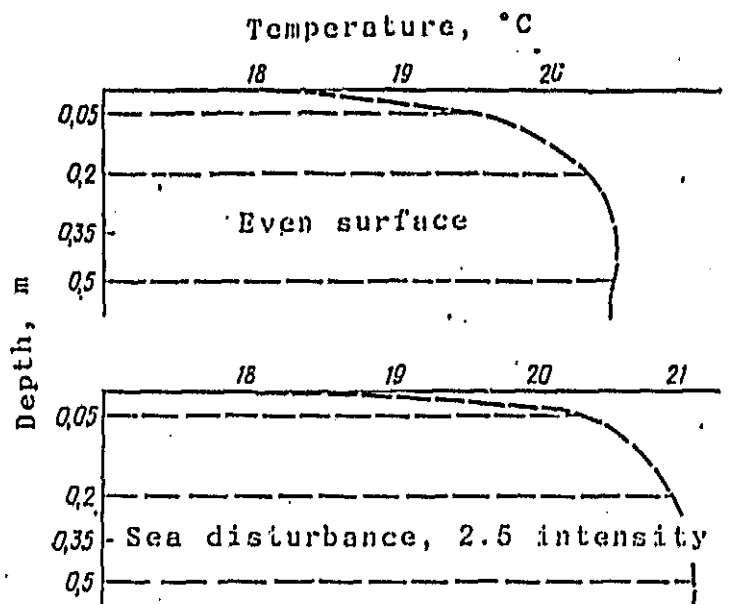
Temperature, °C

Figure 6. Changes in ocean surface water temperature under different conditions.

radiometry's accuracy is low; but this is totally untrue. Space radiometers permit measurements of underlying surface radiation temperature which are accurate to within 0.1 K, and it is this value which should be considered indicative of their accuracy. Here the effect of the atmosphere and cloud cover can be taken into account by calibrating measurement data from test areas, or by using special methods of processing remote probe results.

One such method is the histogram, first used to process data from high-resolution radiometers installed on the Nimbus-series satellites. In this method, all infrared band radiometer information is sorted into small files, corresponding to ocean areas of 2.5 x 2.5° in longitude and latitude. Further, a histogram for the distribution of radiometer signal /30 intensity from each image element is constructed for each file of data. Here, if cloud cover falls into the radiometer's field of view at a given moment it causes a decrease in outgoing signal intensity, since cloud temperature is significantly lower than ocean temperature. Figure 7 shows examples of histrograms obtained in this manner.

Histogram "cold" fronts are strongly distended and not suitable for determining ocean temperature. "Warm" sections are better suited to this task. A preliminary analysis of measurement errors showed that they are determin-d exclusively by radiometer noise, which can be determined in tests of the instrument on Earth (before launch into orbit). The root-mean-square value for noise from the Nimbus satellite's radiometer had been previously determined as 1.5 K.
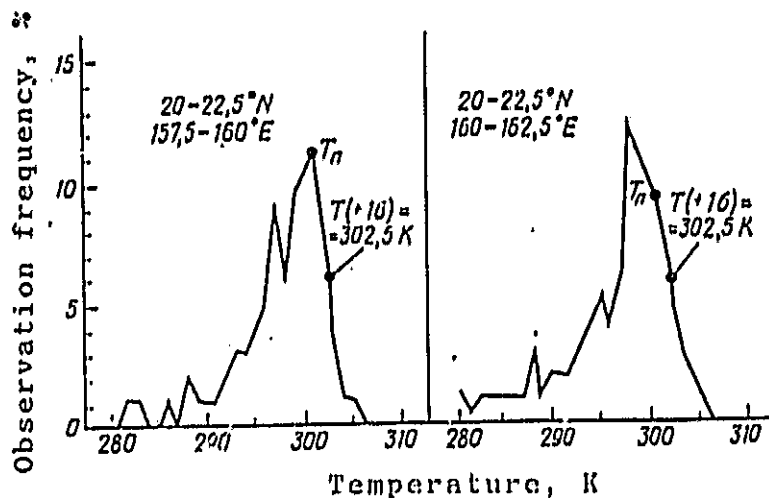
Figure 7. Histograms of surface temperature distribution
for two ocean regions according data from the Nimbus-3
satellite's infrared device.

If this data is taken into account, ocean surface temperature
can be defined as the temperature at the point of maximum slope
on the curve of the histogram's "warm" section minus the root-
mean-square value of radiometer noise. Therefore, ocean surface
temperature measured by the radiometer was 301 K for both   /31
hystograms. At present, this method is widely used to construct
ocean surface temperature charts calculated according to
satellite data.

Soviet scientists have proposed several other methods for
processing satellite infrared measurement data, particularly that
of optimum interpolation, which takes the statistical properties
of the surface temperature field into account. This method
permits exclusion of apparatus noise and cloud cover effects,
but, unlike the histogram, does not result in inferior spatial
resolution of processed information.

In recent years much theoretical and experimental work has
been done to increase the accuracy of transition from radiation
to thermodynamic ocean surface temperature. Work is particularly
being done to construct models of behavior for the ocean surface
layer under different hydrometeorologic conditions. The
development of multizonal infrared measurement methods to
determine cold film parameters experimentally is also very
promising.

The theoretical basis of multizonal methods is the fact that
the effective thickness of radiating film is different for each
wavelength. Therefore, by using simultaneous measurements of
surface radiation intensity in several narrow intervals,

the surface layer temperature gradient can be determined and
taken into account when processing remote sensing data.

Thus, joint processing of dual-channel temperature
measurements taken with the NOAA-6 satellite greatly increased
the accuracy with which the ocean's thermodynamic temperature was
determined. For example, a comparison of satellite data with the
results of synchronized contact measurements of surface layer
temperature taken at one of the subsatellite proving grounds (the
area studied) in the Atlantic Ocean showed that the root-mean-
square deviation between contact and satellite methods was 0.56 K
when surface layer temperatures of 1 to 27°C were measured.
Thus, the accuracy of remote measurements of ocean surface
temperature with infrared range radiometers is completely   /32
satisfactory and makes solving many practical problems possibl°.

The use of infrared apparatus installed on different
satellites has produced several results important for
oceanologists. From 1971 to 1973 the dynamics of the Gulf Stream
current was studied by American scientists using data from the
NOAA satellite's radiometer. The Gulf Stream's boundaries are
clearly visible on many of the infrared images of the Atlantic
Ocean which were obtained then, as are the bends of its axis
(meanders), its eddies and other characteristic formations.
Observations of the western part of the Sargasso Sea showed that
in this region eddies form at Cape Hatteras and move in a south-
westerly direction at an average velocity of around 1.5 km per
day. It was found that the eddies are absorbed by the Gulf
Stream near the Florida peninsula, and that the average life of
an eddy is 2 years.

A scanning apparatus was installed on board the SMS-1
geostationary meteorologic satellite and was used to transmit
images of the Central Atlantic in the visible and thermal
infrared bands of the spectrum to Earth every 30 minutes.
Several of the infrared images were assembled as movie stills,
which permitted visual observation of eddy generation and
movement along the Gulf Stream's southern boundary and the
Florida peninsula.

Several previously unknown zones of "upwelling", that is,
zones where deep waters rich in nutrient substances rise up, were
discovered in the Central Atlantic and several other regions with
data from the NOAA-series satellites' infrared radiometers.

Data from infrared band satellite radiometers is especially
useful for conducting oceanographic experiments in so-called
quasireal time. In these experiments, data from radiometer
surveys of the ocean's surface is immediately transmitted to an
SRS, where it is processed and used to navigate the ship to an
assigned region, the center of an ocean eddy, for example.

Processing of data received from the NOAA-series satellites has been totally automated since 1973. Satellite data is transmitted to two ground receiving stations, after which it is relayed over ordinary communications channels to the processing center, where it is entered into a computer. Daily global temperature charts of ocean surface temperature are the final product of processing. This system determines temperatures accurately to within around,1.5 K.

Many specialist believe that, in the near future, we can realistically expect satellite radiometry measurements of ocean surface temperature which are accurate to within 0.2-0.5 K. Spatial resolution of information obtained will be several hundred meters and the rate of reception up to several times a day. Taking these prospects into account, infrared-band ʻadiometers are scheduled to be installed on all oceanologic satellites currently being developed.

Experiments are now being successfully conducted on construction of infrared lasers (for example, gas lasers which use carbon dioxide gas and have radiation wavelengths of 10.6 microns). Installed on airplanes, these instruments give good results when tackling many problems of interest to oceanologists, for example, determining ocean pollution from petroleum products. Experiments show that instruments of this class are suitable for remote studies of the ocean, and, in principle, they could be installed on board a satellite. Then active probes of the ocean in the infrared band would be possible.

In concluding this section we should note that infrared band information, like that from the visible band, is fragmented even when obtained on a global scale due to the fact that many regions of the ocean are covered by dense clouds and fog. A global study of the ocean without omission is possible only with the use of radio band waves.

RADIOPHYSICAL METHODS OF STUDYING THE OCEAN FROM SPACE

Radiophysical methods of studying the ocean from space, including studies of the atmosphere above the ocean, work in the microwave, or ultra high-frequency (UHF) band of the spectrum on radiowaves from several millimeters to several decimeters long. In this band, formation of the ocean's own thermal radiation or that scattered by its surface is determined by a broad group of hydrophysical parameters, thus making it possible in many cases to obtain information difficult or impossible to obtain when probing the ocean in the optical band of the spectrum.

The transmissivity of the Earth's atmosphere in the radio band is great, and even a cloudy atmosphere is relatively

transmissive. This permits studies with radio methods where it is difficult or simply impossible to use optical methods. Of course, the Earth's atmosphere affects ocean surface radiation detected on board a spacecraft in this band to some degree, but in many cases the effect is small and can be accounted for. There is much less atmospheric interference in the radio band than there is in the visible and infrared bands of the spectrum, and the atmosphere's transmissive function is significantly closer to one.

Thus, according to data from experimental work done by Soviet scientists in the near 0.8 cm wavelength area, a dense layer of cumulus clouds about 1.5 km thick above the Azov Sea completely impenetrable by optical band waves caused a 20-25% change in the so-called radio brightness of the sea's surface temperature. When switching over to 3.2-cm wavelengths, atmospheric contribution decreased even further, and errors in measurement of sea temperature radio brightness caused by the atmosphere decreased to 3 K, that is, they did not exceed 1-2%.

Here the general tendency is the following: longer wave radiation from the ocean passes more freely through the atmosphere without weakening, and can be advantageously used to study the ocean from space. At the same time, studies in the short-wave millimeter area of the spectrum make tackling other assignments possible: evaluating the water content of clouds in the near-water layer of the atmosphere, determining the quantity of water vapor, detecting regions of precipitation, and others related to integrated studies of on-going processes in the ocean-atmosphere system.

In addition, when operating frequency range is being   <u>/35</u> selected, it is necessary to take into account that if the same receiving antenna is used for different wavelengths (and this is often conditioned by the satellite's construction), spatial resolution of information obtained will not be constant. Information obtained on shorter wavelengths will have heightened spatial resolution, while that of information obtained on longer wavelengths will be poorer.

In space oceanology, both remote probe methods, the active and the passive, are widely used in the radiowave band. The active method of studying the ocean from space is based on well-known principles and methods of radar, and the passive, on detection of the ocean's own thermal radio-radiation with sensitive ultra-high frequency radiometers.

Modern satellite UHF-radiometers permit highly accurate, simultaneous determinations of ocean radiation on several wavelengths and in two forms of linear polarization: horizontal and vertical. Strictly speaking, the stream of Earth's radiation received by these devices is made up of the following basic

components: the stream of radiation from the atmosphere layer
located between the surface and the spacecraft; the stream of
atmospheric radiation reflected by the Earth's surface, and the
stream of radiation from the underlying surface weakened by
absorption in the atmosphere. Naturally, only the third
component is of interest to oceanology, while the other two
represent interference.

Even the first experiments, conducted with airplane
laboratories, showed that the degree to which different
oceanologic parameters affect the intensity of ocean surface
radiation (or the radio brightness temperature, which is the same
thing), greatly depends on wavelength. In addition, surface
radiation depends on the angle at which the observation is being
made. The resulting information, as a rule, depends on many
oceanologic parameters at once, and therefore, multifrequency and
polarization measurements must be used to separate different
components and define all parameters in order to carry out   /36
oceanologic tasks accurately and effectively.

For example, when studying oil pollution in the ocean, the
fact that the radio brightness temperature of an ocean surface
covered with petroleum film is higher that of clean water is
used. On 10-cm wavelengths, increase in brightness temperature
is approximately proportional to the thickness of the film and
equal to 1 K per 1 mm of film thickness, which is close to the
sensitivity modern radiometers. It follows that these films can
be reliably identified with radiometers. When switching over to
short wavelengths of several millimeters, the increase in
contaminated surface radio brightness temperature reaches tens of
degrees, i.e., it is more marked.

Remote measurements of ocean surface layer thermodynamic
temperature in the UHF band are based on the fact that radio
brightness temperature is proportional to the thermodynamic. In
the 8-10 cm wavelength band, atmospheric influences and other
interference are minimal and, therefore, this band is the most
appropriate for temperature measurements.

The radio brightness temperature used in radiometry is
related to ordinary thermodynamic temperature through the water's
radio-radiation coefficient. The value of this coefficient
changes greatly depending on observation conditions and many
hydrometeorologic parameters. For many observation angles,
water's radiating capacity is much lower than one and depends
greatly on the degree of polarization of radiowaves used.

Since space studies with scanning devices are conducted over
a wide range of observation angles, it is necessary to take this
dependence into account when processing radiometer data. The
surface roughness coefficient, that is, the degree of ocean
disturbance, has a great effect on the radiation coefficient.

And since the degree of disturbance is closely related to wind velocity in the near-water layer, this parameter can also be studied in this way.

Ocean water's radiating capacity increases especially sharply when foam appears on the surface during strong winds. This foam's radiating capacity is near one in the radio band, and therefore a sharp jump in ocean surface radiation is easily /37 detected on all wavelengths when it appears. And since, as oceanologists well know, foam arises on the ocean surface during winds of more than four degrees of force, this fact permits sure remote definition of storm regions, that is, those dangerous for navigation.

The boundaries of ice fields, and the thickness, density, growth and drift direction direction of ice floes can be determined in a similar manner. The radio radiation of ocean ice covers have their own distiguishing characteristics, and this permits completion of the tasks ennumerated above.

Remote measurements from space in the UHF range can be used to determine variations in ocean water salt content. The long, 20-30 cm wavelength band in the most suitable for this task. On shorter wavelengths the effect of salt content, that is, the corresponding measurement of surface radio brightness temperature, is negligible, and on longer wavelengths, the effect of noise from absorption of ocean radio radiation in the ionosphere and interference from active radars is felt.

Numerical evaluations show that when ocean temperature is 15°C, a 1-percent change in salt content (and average salt content of ocean water is near 35 percent and changes a total of 3-4 percent when moving from the Equator to high latitudes) causes a 0.3 K change in radio brightness temperature on 20-cm wavelengths. Given the existing accuracy of satellite radiometers (0.5-0.8K), it follows that boundaries between fresh and salt water in regions where major rivers flow into the sea and other similar large salt content gradients can be determined.

The first measurements of Earth's own thermal radio radiation from space were made in 1968 with the Soviet Kosmos-243 satellite and continued in 1970 with the Kosmos-384. Ultra-high frequency radiometric studies of Earth were subsequently made in the USSR with the Meteor-series satellites, the Kosmos-669, Kosmos 1076 and Kosmos 115 satellites, the Interkosmos-series satellites, and from on board the Salyut station. In the USA, similar /38 studies were begun in 1972 when the Nimbus-5 satellite was put into orbit. They were later continued on board the Skylab station and with the Nimbus-6, Seasat, and other satellites.

The basic principles for using remote UHF methods to study Earth were developed in the space experiments ennumerated above,

and passive radio methods were shown to be particularly promising
for studying the following characteristics of the ocean and
Earth's atmosphere :

- content of water vapor in the atmosphere and its
  distribution above the ocean;
- cloud moisture content and evaluations of draught
  intensity;
- studies of ocean surface temperature;
- determining boundaries of storm regions;
- determining boundaries and status of ice floes;
- detecting oceanic oil pollution.

UHF-radiometric apparatus installed on the Kosmos-243 and
Kosmos-384 made obtaining ocean surface radiation on 0.8-, 1.35-,
3.4- and 8.5 cm wavelengths possible. The fluctuation
sensitivity of these first radiometers was 1 K at constant time
of 1 second. All radiometer antennas were directed vertically
downward and scanned a path along the AES's flight track. The
linear dimension of the surface area which fell into the
antennas' field of view (spatial resolution of information
obtained) was around 50 km on 8.5-cm waves and 20 km on short
waves.

The radiometers' temperature scales were calibrated with a
special noise generator periodically switched onto the radiometer
input channel in place of the receiving antenna. Space
background radiation received by small horn antennas was used as
the radiometers' reference signal.

Joint processing of data obtained from all four radiometers
made it possible to determine the distribution of several
oceanologic parameters along the AES flight path. Measurements
of one of these basic parameters - ocean surface temperature -
were accurate to within 1-3 K in this experiment.

Two instruments for passive probes in the UHF band were   /39
installed along with regular optical band meteorologic apparatus
on both the American Nimbus-5 and Nimbus-6 satellites. One of
these was a 5-channel radiospectrometer measuring underlying
surface radiation intensity at frequencies of 22.23, 31.65, 52,86
and 55.44 Hz. The other was a single channel scanning radiometer
working on 1.55-cm (Nimbus-5) and 0.8-cm (Nimbus-6) wavelengths.
The latter two apparatus were used to obtain the first radio
images of the Earth from space.

The Nimbus radiometers' sensitivity was 0.5-0.8 K. Accuracy
of ocean surface temperature measurements using data from these
experiments was approximately the same as that of experiments
conducted with the Kosmos-series satellites, and the spatial
resolution was approximately one order of magnitude poorer (due
to the high orbit altitude).

Active methods of studying the ocean from space in the radio band have been developed along with passive methods in recent years. When active methods are used on board a spacecraft, a powerful source of radio radiation is installed and its energy is directed downward to the ocean. The radio waves reflected by the ocean surface and scattered by its aqueous depths return and are detected with special receivers. An analysis of the signals received makes it possible evaluate oceanologic parameters of interest.

These simple concepts of studying the ocean from space have proven extremely fruitful, and at present much experience has already been accumulated in the use of active radio methods in space oceanology. In the past few years three instruments for active studies of the ocean in the radio band have been tested in space: scatterometers (for measuring back scatter coefficients), altimeters and lateral scanning radars.

Use of radar scatterometers in space oceanology is based on the fact that the statistical properties of reflected radio signals are a function of those of the reflecting surface. Using this phenomenon it is possible to study the characterictics of wind disturbance on the ocean surface with remote methods, since this disturbance determines ocean surface   /40 irregularities and roughness.

When the ocean surface is irradiated with radio waves, those waves which fulfill the so-called resonance scattering condition are reflected especially intensely. During oblique irradiation, resonance scattering is observed on ocean waves approximately half as long as the wavelengths of the sensing radio impusle.

The so-called backscatter cross-section is a measure of the instensity with which incident radiation is scattered by the surface being studied. A given value is proportional to the frequency of incident radio radiation and the average frequency of waves on the agitated ocean surface. This underlies the study of spectra of scattered ocean disturbance elements according to backscatter cross sections of sensing radio signals measured by a spacecraft. It also makes determining the average height of ocean waves possible, since the amplitude of the return signal received by the scatterometer is proportional to the root-mean-square of wave height.

Just as important is the fact that the characteristics of wind disturbance are closely related to wind strength in the near-water layer of the atmosphere; consequently, scatterometers' potential for defining this parameter remotely from space makes makes them especially valuable. As a result of the rapid movement of a spacecraft in orbit, the scattered signal received by the scatterometer will have a definite Doppler shift depending on the angle of radio wave radiation in relation to flight

direction. This must be taken into account when using receiving-transmitting antennas with wide beam patterns.

Surface irradiation with oblique beams is used in space scatterometry to better clarify the statistical properties of reflecting surfaces. The first experiments showed that sensing radio impulses with striking angles in the 30-60° range can be used. This fact makes it possible to scan an area of ocean surface equal to or even greater than the orbit altitude   /41 during a spacecraft's flight.

Radio altimeters have opened up great possibilites for studying the ocean from space. The concept of the radio altimeter is as simple as those of other remote methods. If the time it takes a sensing radio impulse to travel from the spacecraft to the ocean surface and back is accurately measured, then it is easy to calculate the distance from the spacecraft to the ocean surface. This method was long limited by insufficiently accurate measurements, but at present progress is this area of radar makes determining distances accurately to within tens or even single centimeters possible, while trajectory parameters can be determined with equal accuracy with special laser measuring assemblies.

Therefore, the spacecraft's orbit can be used as a reference line in space radioaltimetry and ocean surface profiles can be measured relative to it with altimeters. Large-scale irregularities in surface relief caused by anomalies of the Earth's gravitational field, ocean currents, tsunami waves, rising storms and other phenomena can be detected in this way. Besides solving these problems, space altimeters can also be used to successfully complete studies of ocean disturbance distribution along the satellite's flight trajectory, as we have already seen.

A space altimeter radiates a short, square-wave radio impulse, but the return impulse reflected by the ocean surface is significantly transformed. First of all, the reflected impulse fronts are very blurred, and the blowup of the leading front (slope of its leading edge) is basically determined by the magnitude of ocean disturbance in the subsatellite point. Signals reflected from agitated surface elements of different heights do not arrive simultaneously. The stronger the ocean disturbance in the subsatellite point, the more the sensing radio impulse blurrs. This relationship can be used to measure wave heights, which is the second, equally important, use of   /42 altimeters.

In order to increase the accuracy of space altimeter measurements of oceanologic parameters, sensing impulses are sent in short series with subsequent statistical processing of reflected radio signals. To measure ocean disturbance with

acceptable accuracy (up to 0.5 m), it is necessary to use altimeter radio impulses no more than 3 ns (Newton seconds) long. Since the irradiated spot of ocean surface is several kilometers in diameter, calculations must assume that the disturbance field within it is uniform.

The slope of the trailing side of the sensing impulse, as data from experiments has shown, is basically determined by the errors in orientation of the spacecraft relative to local vertical, and this data can be used to control the spacecraft's angular position.

In the opinion of many experts, one of the most promising instruments for space studies of the ocean is the lateral scanning radar (LSR). These instruments make it possible to obtain "radio images" of ocean surface on which several oceanologic phenomena, such as massive waves, are immediately visible. The LSR can be used to determine ice field boundaries, study the statistical characteristics of disturbances, determine ocean pollution by petroleum products and solve several other oceanologic problems. All phenomena which transform ocean surface disturbance can be studied with these instruments.

The lateral sweep of ocean surface images formed with space LSR is attained with temporal selection and processing of reflected radio impulses; the longitudinal sweep with the satellite's orbital motion. LSR can be used to obtain patterns of ocean disturbance relatively quickly and over large areas. The LSR must use short sensing impulses, and its radiating antennas must have narrow beam patterns in the horizontal plane   /43 in order to obtain information with high spatial resolution (up to 50 m). In the face of current limitations in spacecraft antenna dimensions, this resolution can be achieved only if the LSR has a synthesized aperture.

In outward appearance, ocean surface radio images obtained with LSR somewhat resemble space photographs obtained with ordinary cameras. On these radio images, portions of agitated ocean surface appear lighter, since they scatter incident radio radiation better. On the other hand, a spot of oil pollution will look darker on the radio images, since a "smoothing out" of surface disturbance occurs there and the amount of backscattered LSR radiation energy decreases. Computer processing of LSR information is especially effective. In this case phenomena which are not visible on "unprocessed" radio images of the ocean can be detected.

Active radiophysical methods of studying the ocean were first tested in 1973 during the flight of the Skylab station. The station was put into a circular orbit with an altitude of 440 km and a 50° angle of inclination to the plane of the Equator. Two radar instruments were installed on Skylab: a scatterometer and

a high frequency radio altimeter. The joint antenna structure
for these two instruments made mechanical ray scanning of ±50° in
two orthogonal directions possible. The main antenna lobe's beam
pattern was 1.5° wide at an altimeter operating frequency of 13.9
Hz.

Measurements of the ocean surface profile with this altimeter
had a relative accuracy of around 1 m. The space radio
altimeter's impulse lasted from 10 to 130 ns. Impulse frequency
in the altitude measuring mode reached 250 impulses a second,
which made it possible to obtain up to 8 altitude surveys per
second after statistical processing of reflected signals; that
is, spatial resolution of data from Skylab's radiometer was
around 1 km along the flight track. The radiometer's capacity to
radiate impulse energy reached 2 KW.

More than 150 series of radiophysical experiments were   /44
made by three crews during Skylab's flight. Even these first
tests of active space radio methods produced several important
results. Processing of scatterometer data showed that this
instrument can be used to measure ocean surface disturbance with
waves more than 1 m high and to determine wind strength and
direction in the near-water air layer. Scatterometer wind force
measurements were accurate to within around 10% when wind changes
were 0 to 20 m/s. It is especially important to note that wind
and disturbance distribution in tropical cyclone (hurricane)
zones was studied several times with the Skylab scatterometer;
this has special significance for oceanologists and navigators.

Experiments with space radio altimeters also proved very
successful. Satellite altimetry's fundamental potential for
solving oceanologic problems was visually demonstrated for the
first time in these experiments. Thus, geoid surface shape near
several gravitational anomalies was more accurately defined with
data from Skylab's altimeter, and many interesting facts
previously unknown to science were learned. For example, it was
visually demonstrated the that ocean's surface sags slightly
above regions of deep water troughs and channels, as though
imitating the form of the ocean floor. Above underwater ridges
and mountains rising several kilometers above the ocean floor
("guyots"), the opposite picture is observed – as though a
distinctive dome were growing above the ocean surface in this
case.

This data particularly helped define ocean surface form near
the famous Bermuda Triangle more clearly. The so-called Puerto
Rican trough is located in this region, and, as measurements
taken from onboard Skylab showed, the gravitational anomaly
related to the trough is evidenced by lower average ocean level
above it. The upper portion of Figure 8 shows Skylab's flight
path from the shores of South Carolina in the USA to the island

of Puerto Rico in the Central Atlantic. The lower portion of the drawing shows results of measurements of ocean surface profile taken with the altimeter and data from ordinary depth soundings.

The upper curve shows the difference between the level of Earth's ellipsoid and the altitude measured with the altimeter. Lower ocean surface profile above the so-called Blake drop, a slight rise above an underwater plain region and a 15-m depression (trough) nearly 100 km in diameter above the Puerto Rican trough are clearly marked on this curve. It is interesting that altimeter data clearly shows the difference between slopes of the trough's northern and southern sides.
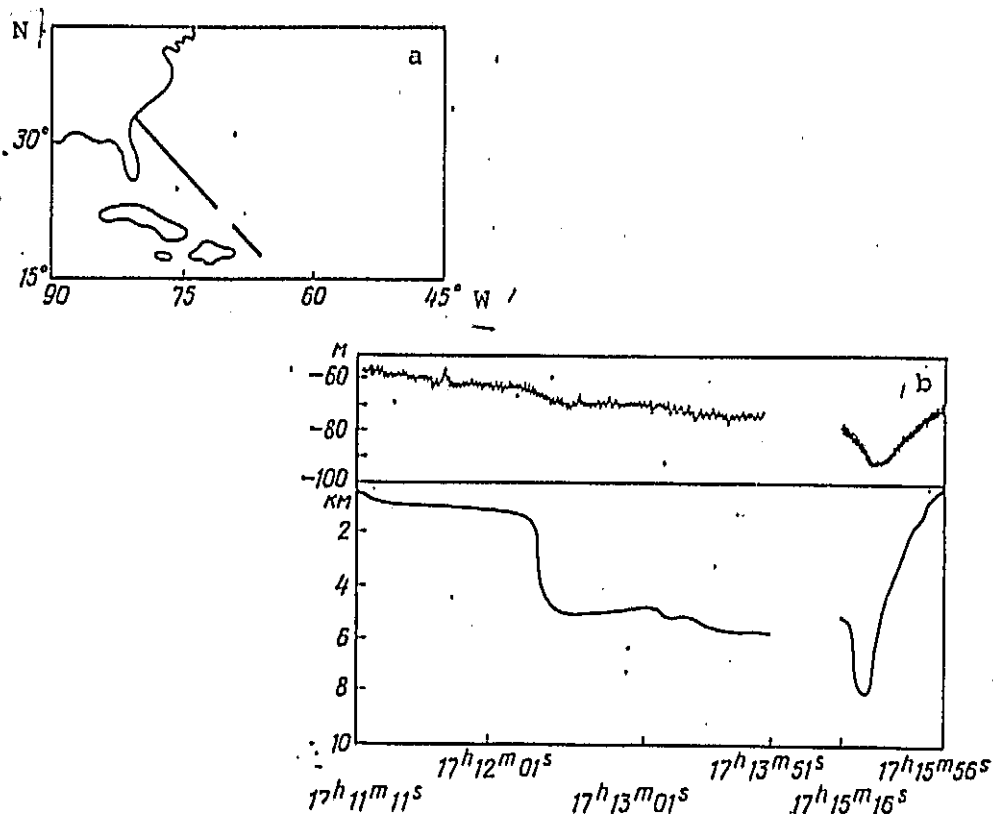
Figure 8. The Skylab station's flight path in one of its orbits. (a), ocean surface relief according to altimeter data (upper curve) and data from geographical depth soundings in this region of the ocean (lower curve). Along the vertical line (b), ocean surface deviation in meters and ocean depth in kilometers; along the horizontal line — flight time.

Naturally, all these troughs and domes on the ocean surface are relatively small and no more than 10-20 m long. And since horizontal dimensions of these ocean surface "irregularities" run

into tens and hundreds of kilometers, they are completely
unnoticeable when measurement is done on a SRS and cannot be
detected with traditional methods.

A second experiment in space altimetry was made in 1975 after
the GEOS-3 satellite was put into orbit. This AES was put into a
circular orbit with an altitude of 840 km, and it carried an
altimeter measuring basically the same characteristics as did
Skylab's. As a result, extensive regions of the ocean were
studied and new data on surface form was obtained. Use of these
altimeters revealed, for example, a change in surface level near
major ocean currents such as the Gulf Stream or the Kuroshio.

The results of experiments conducted on board Skylab and with
the GEOS-3 AES satellite demonstrated that active radio methods
can be an effective all-weather means of studying the ocean from
space. In the opinion of many, instruments used for these
purposes will be the basic operating instruments of oceanologic
satellites being developed to track ocean conditions in any
weather, both day and night.

FIRST-GENERATION OCEANOLOGIC ARTIFICIAL EARTH SATELLITES

As has already been noted, the first specialized, purely
oceanologic satellites were put into orbit in the USSR and USA
toward the end of the 1970's and the beginning of the 1980's.
They were equipped with the various remote sensing instruments
described in previous sections, but instrument integration,
operating characteristics, and distribution according to
priority and importance of experiments conducted was determined
by the specific flight program of each individual satellite and
the purpose of the experiments as a whole.   /47

Let us look at the American Seasat satellite, whose name is
an abbreviation of the English words "sea satellite", as a
typical example of technical equipping of a first generation
oceanologic AES. The Seasat project was begun in 1974 under the
aegis of NASA's Applied Programs Administration. At the moment
of its launch, the cost of developing Seasat had reached $95
million, which is much higher than the cost of many other
experimental AES. This was due to the unique nature of the
research equipment installed on board the satellite, which is
highly indicative of the complex problems confronting designers.

More than 25 major government organizations and private firms
closely related to ocean research programs took part in
developing Seasat and its flight programs. The satellite's
structural basis was the final stage of the Agena carrier rocket,
whose energy, control and telemetric systems were used. After
its launch into orbit, the satellite weighed around 2300 kg, and
its solar battery panels and antennas spanned 13 m. Satellite

orientation and stabilization in the orbital coordinate system
were up to 0.5° accurate. Capacity of the electrical power
supply system for scientific apparatus was around 2 KW.

Figure 9 shows a general view of Seasat with unfolded
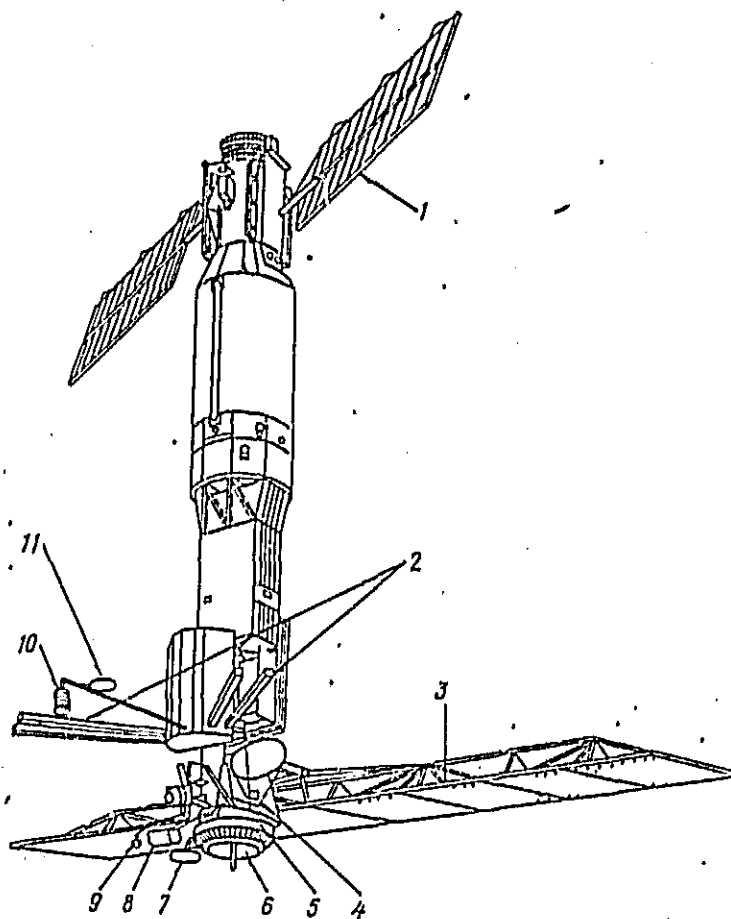antennas and solar battery panels.

Figure 9. General view of the Seasat oceanologic
satellite: 1 - solar battery panels; 2 - scatterometer
antenna; 3 - SVRL antenna; 4 - multichannel UHF-radiometer;
5 - laser reflector; 6 - altimeter; 7 - SVRL telemetric
antenna; 8 - infrared and visible range radiometer; 9 -
telemetric and command radio line antenna; 10 - orbit
parameter determination system antenna; 11 - telemetric
system back-up antenna.

An assembly made up of five scientific devices was installed
on board Seasat, and these devices were distributed according to

the importance of experiments conducted in the following manner:

1. radio altimeter,
2. scatterometer,
3. lateral scanning radar with synthsized aperture,
4. visible and thermal infrared scanning radiometer
5. multichannel scanning microwave radiometer.

In addition to this scientific equipment, three different systems for accurate trajectory measurements of orbit paramters were installed on board.

Directed vertically downward (to the nadir), the /48 altimeter had a 1.6° field of view, which corresponded (depending on the intensity of ocean disturbance in the subsatellite /49 point) to the spot on the ocean surface 1.5 to 12 km in diameter being studied. The instrument operated on a frequency of 13.5 Hz and radiated sensing impulses 3 ns wide, which permitted measurements of satellite altitude above the ocean surface with a root-mean-square error of 10 cm when ocean waves were up to 20 m high. This instrument also made it possible to accurately define wave height in the subsatellite point to within 0.5 m (in the 0-20 m range).

The Seasat scatterometer operated on a frequency of 14.6 Hz. The beam pattern of each of its four antennas was a "knife-blade", that is, narrow in the horizontal plane and wide in the vertical, which permitted irradiation of two areas of ocean surface 500-700 km wide and 200 km away from the flight track. Spatial resolution of Seasat scatterometer information was around 50 km. Detection and processing of Doppler shifts in reflected signals made it possible to determine wind velocity on the ocean surface with an accuracy of up to 2 m/s (in the 4-26 m/s range). Evaluation of wind velocity direction was accurate to within 20°.

The LSR with synthesed aperture designed to obtain radio images of the ocean surface operated at 1.275 Hz. It scanned an area 100 km wide at an angle of 20° relative to the vertical.

High spatial resolution of information obtained with the radar (up to 25 m) determined the rapid rate at which this information was received and its high volume. After preliminary analysis different data registration and transmission systems, it was decided that this instrument would operate only in the immediate transmission of information mode - that is, without intermediate onboard recording. Naturally, this substantially limited regions where research could be conducted with the LSR.

The antenna of Sisat's LSR had a gain of 34 dB and formed fan-shaped rays deflected 20° relative to vertical direction with angular dimensions of 1 x 6°. During the flight of the satellite, this instrument was used to irradiate a band of ocean

surface 100 km wide and 250 km away from the flight path. /50
The same antenna was used to receive radiation reflected from the
ocean surface. After amplification, the transformed signals were
sent to the telemetric system and immediately broadcast to a
ground receiving station at a velocity of 10 mbits/s. Due to
these circumstances, the LSR could continuously study a band of
ocean surface no more than 4,000 km long.

The visible and infrared-band radiometer (two channels with
0.45-0.94 and 10.5-12.5 - micron wavelengths) was an ordinary
scanning radiometer, prototypes of which had been installed many
times on meteorological satellites. It was used to obtain images
of the underlying surface in the visible and thermal infrared
bands of the spectrum. This made it possible to identify cloud
cover along the flight trajectory and determine cloud and ocean
surface temperatures.

This instrument's resolution capacity was 2 km for the
visible band and 4 km for the infrared band. The radiometer was
used to scan a band of ocean surface 1100 km wide. According to
preliminary evaluations, determination of ocean surface layer
temperature with data from its infrared channel was better than 1
K accurate.

The centimeter band multichannel scanning microwave
radiometer made it possible to measure the ocean - atmosphere
system's thermal radiation on 3.8-, 2.8-, 1.65-, 1.43- and 0.8 cm
wavelengths with vertical and horizontal radiation polarization.
Similar instruments had been installed on the Nimbus series
experimental meteorological satellites, where they were used to
determine atmosphere parameters. A long wave channel (3.8 cm
wavelengths) for microwave measurements of ocean surface
temperature was added to the instrument on board Seasat.

Spatial resolution of information obtained with this
instrument depended on the freqeuncy being used and ranged from
100 km (for long waves) to 20 km (for the shortest). The
radiometer's antenna could scan at an angle of around 40° in the
plane of orbit, while scanning area in the lateral direction was
around 600 km wide. This radiometer was used to determine /51
determine ocean surface temperature and the magnitude of wind
velocity on the ocean surface, as well as moisture and water
vapor content along the flight track. Absolute accuracy of
temperature measurements was 2 K, and determinations of wind
velocity magnitude in the near-water air layer were accurate to
within 2 m/s (when measuring weak to storm winds).

Seasat was launched on June 28, 1978 into a circular orbit
with an altitude of around 800 km and an inclination of 108°.
The orbit was not solar-synchronous because the flight program
was designed to obtain information on the ocean at different
degrees of illumination by the Sun. Daily shift of the flight

path (18.5 m) was selected to ensure thorough "coverage" of the ocean's surface by the radio altimeter, which had a relatively narrow field of view. Repeat ocean observation conditions were to occur every 152 days.

Satellite instruments covered a wide band of ocean surface (scatterometer and scanning radiometers) and ensured a view a 95% of the ocean surface every 36 hr, in other words, a fairly high rate of observations and information renewal. Calculated functioning time for all operating systems and scientific equipment was more than one year. However, on October 10, 1978 all scientific equipment on the satellite went out of order as the result of a short circuit in the electrical supply system.

After 100 days of active work, Seasat had completed 1502 orbits around the Earth. During this time two series of integrated subsatellite experiments were conducted in the eastern part of the Atlantic Ocean and Alaska Bay. The satellite had completed neary 260 passes over subsatellite research control proving grounds. Methods of immediate contact measurement at these proving grounds included ocean buoys, and the Oceanographer, Quadra and Vancouver SRS's. In addition to standard meteorological observations on all SRS's, a special program was conducted on measuring wind and ocean disturbance characteristics at the time of the satellite's pass overhead.

Also taking part in subsatellite observations were four /52 airplane laboratories which measured wind velocity at different altitudes, air and ocean surface temperature, and ocean disturbance parameters along the satellite's flight path. Ocean observation data from ordinary cargo ships and information from geostationary and other satellites was used when processing information from Seasat.

Considering the great complexity and high cost of Seasat's equipment, a project for returning the satellite to Earth for repair is being proposed. At present, work on creating a new ocenologic satellite, Seasat-2, is being done in the USA. This AES, equipped with approximately the same group of research equipment as its predecessor, is scheduled to be launched into orbit toward the end of the 1970's.

USING ARTIFICIAL EARTH SATELLITES FOR MARITIME COMMUNICATION AND NAVIGATION

Collecting information with automated oceanologic buoys has long been considered one of the basic direct contact methods of obtaining information on the ocean in oceanology, especially during prolonged measurements. Special oceanologic buoys with devices for immediate contact measurements are either set up on

anchors rom onboard an SRS, or allowed to drift freely in the area of . :terest to scientists. Information obtained from the buoy is transmitted to the SRS drifting nearby or recorded on automated buoy recorders.

Working with buoys is fairly simple and effective, but it does have several shortcomings. First of all, when work is organized this way, it is necessary to keep an SRS near the installed buoy. This is not always desirable, and it sometimes distorts sensor signals and leads to losses in time and resources. Immediate transmission of information to shore, frequently at distances of several thousands of kilometers, is complicated and costly, since it is necessary in this case to install a powerful automated radio station on each buoy.

Obviously, this work could be more easily done by using an intermediate retransmitter, and installing this   /53 retransmitter on a satellite is best of all. Then it is possible to set up a simple, small and reliable ultra short-wave transmitter on the buoy, with its antenna trained upward. The buoy's oceanologic sensors are periodically read with special commutators and the signals obtained are recorded on a buffer recorder.

When the satellite passes over the buoy, this transmitter is turned on and it sends accumulated information to the satellite, where it is first recorded on board, and later "dumped" downward when the satellite passes over a ground communications point. Information is further distributed among users over ordinary ground communications channels.

Relay satellite orbits can be selected so that communications sessions between the satellites and buoys and transmission of information from buoys occur at least once a day. In principle, if the satellites' orbits are high enough and the data gathering system is equipped with enough satellites, then transmission of oceanologic information from buoys can be even more frequent, or even continuous.

Various types of such satellite systems for gathering and transmitting information (SSGTI) were developed in the USSR, GDR, USA, France and other countries and successfully tested on several AES. In particular, devices for working up a SSTGI developed by specialists from socialits countries were installed on the Interkosmos-20 and Interkosmos-21 AES. It was possible to install 31 sensors on each buoy in this system, which were read in 30- to 60-minute cycles.

During a communications session between satellite and buoy, the distance between them can be determined and used to calculate the buoy's position in the ground coordinate system. These automatic systems for determining buoy coordinates open up broad

vistas for using free-drifting buoys and following their movements. They will also make searching for buoys, servicing them, etc., easier. Here buoy coordinates are accurately determined to within 1-3 km, which is good enough for completion of many practical assignments.

Basic data on the French-American Argos system, which has functioned since 1978, is given here as an example of the /54 technical characteristics of modern SSTGI's.

System's work area - the entire face of the Earth
Type of relay satellite - Tiros-N meteorological AES
Relay satellite's orbit altitude - 830 km
Type of orbit - polar or solar-synchronous
Maximum number of buoys serviced by the system - 16,000
Average frequency of buoy sensor readings from AES - 3.5 hr
Number of measuring channels on each buoy - 32
Length of buoy sensor reading - 40-200 sec
Operating frequency of buoy transmitter - 401 MHz
Combined weight of service equipment for buoy - 1.5 kg
Service equipment energy consumption - not more than 200 MW
Time required to process preliminary information from the
     moment of its transmission from the AES to the moment of
     its transmission to the user - not more than 6 hr
Cost of one set of buoy equipment - not more than 10
     thousand francs.

Satellites are now being widely used to navigate industrial, transport and scientific ocean vessels. Satellite navigation systems are currently installed on almost all large SRS's, and this is due to several key advantages of such systems. They function in any weather, in rain and fog, and their work is much more accurate than that of traditional optical and long-distance radio systems. Ship equipment presently used for satellite systems is small and lightweight.

The concept behind using satellites to navigate ships is quite simple. The satellite moves in an orbit whose parameters can be measured and predicted quite accurately - to within several meters. If at some point in time the distance from the ship to the AES or the velocity at which this distance changes is measured, it is then easy to calculate the ship's coordinates at the moment of communication. Here the principle is the same as that used to determine buoy coordinates in the SSTGI. Several satellites can be used simultaneously in the satellite navigation system, and this makes navigation measurements in cycles of less than an hour possible.

The Transit American satellite navigation system, for example, is built on this principle. Commercial use of the system began in 1967, and it is presently used by tens of thousands of ships located at different points on the ocean. Six

satellites revolving around the Earth in polar orbits <u>/55</u>
1075 km in altitude are used in the Transit system. The user has
10-15 min sessions of observation time with each satellite to
determine coordinates, and during this time the AES passes over
several thousand kilometers.

Use of polar orbits for navigation satellites makes working
with the system in any region of the ocean possible.
Interruptions in navigation observations are longest at the
Equator at 80 min. The root mean square accuracy with which the
Transit system determines ship coordinates is around 100 m.

This is the level which has already been attained. The
promising Navstar satellite navigation system, currently being
developed, should accurately determine ship position to within
around 5 m. This system will include 24 satellites whose
circular orbits will have altitudes of nearly 20,000 km and an
inclination of 63°. This arrangement of satellites will help
ensure radio visibility of no less than 6 system satellites from
any point on Earth's surface at any given time, which is
necessary for continuous determination of navigation parameters
in real time.

Ship equipment for satellite navigation systems used at
present is small, lightweight and low in energy consumption.
Thus, the device developed for installation on small ships only
weighs a few kilograms and consumes no more than an ordinary
light bulb.

Of course, using satellites for navigation does not bring
scientists new information on the ocean, but it does permit more
effective completion of many traditional oceanologic tasks. For
example, accurate departure of an SRS for any point on the ocean
has become possible with satellite navigation systems. Valuable
expedition time is no longer spent searching for buoys previously
left behind or for bottom stations. When conducting research
from a drifting SRS, drift parameters can be accurately
determined and taken into account when processing information.

One of the most recent examples using satellites to solve
"ocean" problems is their use for communicating with ships. <u>/56</u>
Ordinary short-wave and low-information maritime systems are
already unsatisfactory for scientists, who must often transmit
large streams of information to on-shore centers (or from them to
the SRS) for computer processing, for example. Ordinary ultra
short-wave communications systems are of no help in this case,
since they have a limited radius of action due to the curvature
of the Earth.

To sucessfully complete this task, an intermediate
retransmitter is once again necessary; and again, satellites can
serve this purpose. Satellite communications systems (SCS) for

dry land have functioned since the beginning of the 1960's. But since they were designed to transmit information from one continent to another, these systems are not suitable for use at sea due to their large overall antenna dimensions and highly complex communications equipment.

At present communications equipment has reached such a degree of miniaturization that it can be installed on almost any vessel. In one maritime SCS (the Soviet Volna-S system), the antenna of the ship's receiving-transmitting station is 1.5 m in diameter and mounted on a hydrostabilizing platform. On command from a special computer unit it is trained on a specific point in the heavens (where the communications satellite is located) with an accuracy of around 1° during any type of motions.

As a rule, maritime SCS's use relay satellites in stationary orbits. This makes training the antenna much easier and allows a system with fewer satellites. Thus, there are only three geostationary AES's in the American Marisat system, one above the Atlantic (standing point 15° West), Indian (73° East) and Pacific (176.5° East) Oceans.

In September 1976, at a session of the Intergovernmental Maritime Consulting Organization (IMCO), an agreement was signed on creating the first international system of communication and navigation for maritime fleets, the Inmarsat system. Several dozen governments are taking part in creating and financing this system, the USSR among them. Inmarsat will be set up from 1983 to 1985, and will use retransmitters installed as payload /57 on the Intelsat, Marex and Gorizont communications satellites.

Finally, in concluding this section, the prospect of creating a satellite system for locating ships in distress at sea might be mentioned. The gratifying assignment of protecting and saving the lives of those working at sea will also be carried out with satellites.

The Soviet Union is currently participating in the international Kospas-Sarsat project to create such a system. Under this project, special transmitters which automatically switch on in an emergency situation will be installed on ships and airplanes. Special satellites will recieve the signals from these transmitters, determine their coordinates and relay emergency information to on-shore centers, two of which are being built in the USSR. Experimental operation of this system is slated to begin in 1982.

Despite the fact that space methods have produced individual interesting results, their contribution to the overall program of research on the ocean is still totally insufficient. This is due above all to the imperfection of both remote probe equipment and methods of processing information transmitted from space, and

much work in these directions still lies ahead. Nevertheless, we already have several examples of how highly effective space methods are, not only for studying the ocean, but also for solving problems important to the national economy.

Space photo-information, including photo-information on the ocean, is now being used by many organizations and has saved an estimated hundreds of millions of rubles a year.

Thus, methods of studying the ocean from space have convincingly demonstrated their usefulness and promise, but this does not mean that in the near or distant future they will completely take the place of traditional ship measurements. It is obvious that, in the future, with intelligent unification of these diverse methods of oceanologic studies, space methods will occupy a worthy place in a promising, integrated system of studying the ocean.

In any case, initial tests of space-based reasearch   /58 on the ocean have demonstrated that we can look forward to more major advances and discoveries in this new area of science in the immediate future.

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